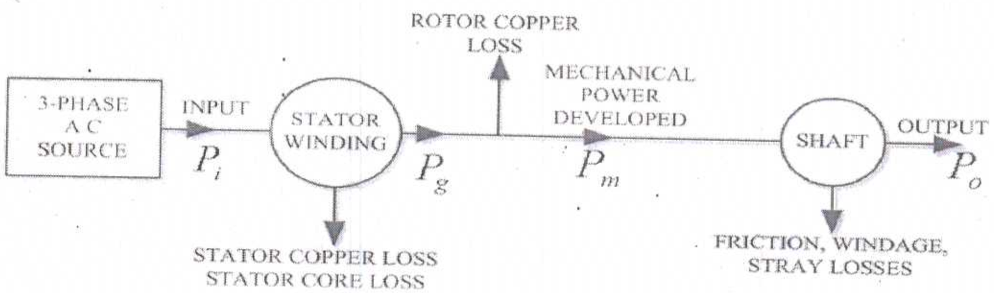
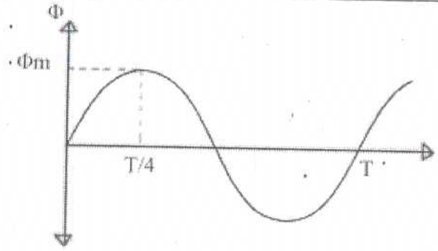
Scoring Indicators

Code : 5031 Induction Machines **Version:**

Qn. No.	Scoring Indicators	Split score	Total score
	PART - A		
I.1.	Transformation ratio is ratio between secondary voltage to primary voltage. ie. $K = V_2/V_1 = N_2/N_1 = I_1 / I_2$ Turns ratio is the reciprocal of transformation ratio or primary turns to secondary turns. Turns ratio = 1/K	1+1	2
I.2.	All day efficiency means the power consumed by the transformer throughout the day. It is defined as the ratio of output power to the input power in kWh or Wh of the transformer over 24 hours.	2	2
I.3.		2	2
I.4.	Normal Starting torque, high starting current with Low Slip is the required operating criteria of this type of motor with high full load efficiency. Examples: Fan, Blowers, Machine tools, etc. High Starting torque, low Starting current and applicable for a constant speed-load condition is the required operational criteria for this type of motor. Examples: Compressor, Crushers, Conveyors, etc. Highest Starting torque of all the class motor, low starting current and high operating slip. This type of motors has low efficiency suitable for intermediate loads. Examples: Bulldozers, Die stamping, etc.	0.5 x 4	2
I.5.	Three phase transformer connections. Windings of a three phase transformer can be connected in various configurations as (i) star-star, (ii) delta-delta, (iii) star-delta, (iv) delta-star, (v) open delta and (vi) Scott connection.	0.5x4	2
	PART – B		
II.1	EMF Equation Of The Transformer Let, N1 = Number of turns in primary winding, N2 = Number of turns in secondary winding, Φm = Maximum flux in the core (in Wb) = (Bm x A), f = frequency of the AC supply (in Hz); emf equation of transformer		



	As, shown in the fig., the flux rises sinusoidal to its maximum value Φm from 0. It reaches to the maximum value in one quarter of the cycle i.e in T/4 sec (where, T is time period of the sin wave of the supply = 1/f). Therefore, average rate of change of flux = Φm /(T/4) = Φm /(1/4f) Therefore, average rate of change of flux = 4f Φm .... (Wb/s). Now, Induced emf per turn = rate of change of flux per turn Therefore, average emf per turn = 4f Φm ....(Volts). Now, we know, Form factor = RMS value / average value Therefore, RMS value of emf per turn = Form factor X average emf per turn. As, the flux Φ varies sinusoidal, form factor of a sine wave is 1.11 Therefore, RMS value of emf per turn = 1.11 x 4f Φm = 4.44f Φm. RMS value of induced emf in whole primary winding (E1) = RMS value of emf per turn X Number of turns in primary winding $E_1 = 4.44f N_1 \Phi m$ .... eq 1 Similarly, RMS induced emf in secondary winding (E2) can be given as $E_2 = 4.44f N_2 \Phi m$. .... eq 2 from the above equations 1 and 2,emf equation of transformer	6	6
II.2.	For dry type transformers Air Natural (AN) Air Blast For oil immersed transformers Oil Natural Air Natural (ONAN) Oil Natural Air Forced (ONAF) Oil Forced Air Forced (OFAF) Oil Forced Water Forced (OFWF) (explanation)	1.5x4	6
II.3.	Generator No of poles (P) = 8, speed (N) = 750 rpm ,then frequency (f) = PN/120 = **50Hz** Motor No of poles (p) = 6, slip = 3% =0.03 , synchronous speed Ns = 120 x50 /6 = **1000rpm** then speed of motor (N) = Ns – S Ns = 1000 – 30 = **970rpm**, Frequency of rotor (f') = Sf = 0.03 x 50 = **15Hz.**	1.5x4	6
II.4.	(i)actual measurement of rotor speed (ii)by measurement of rotor frequency (iii) stroboscopic method In the first method the speed of rotor is measured and then subtracted from the synchronous speed to give slip. Slip = Ns – N. In second method a centre zero moving coil multi voltmeter inserted in the rotator circuit. The deflection of meter can give the frequency of rotor. From this the slip can measure by the relation , slip S = rotor frequency / supply frequency.		

In third method a stroboscopic disc is used for this measurement. The complete apparent revolution of the disc are counted in a given time and slip is determined by the following relation

Slip = apparent revolution counted in the given time X pair of poles / total time X supply frequency. **(any two method + explanation)** **3x2** **6**

II.5

Changing The Applied Voltage
Changing The Applied Frequency
Constant V/F Control Of Induction Motor
Changing The Number Of Stator Poles
Rotor Rheostat Control
Cascade Operation
By Injecting EMF In Rotor Circuit (any six) **1x6** **6**

II.6.

The torque produced by three phase induction motor depends upon the following three factors:

Firstly the magnitude of rotor current, secondly the flux which interact with the rotor of three phase induction motor and is responsible for producing emf in the rotor part of induction motor, lastly the power factor of rotor of the three phase induction motor.

Combining all these factors, we get the equation of torque as-

$T \propto \phi I_2 \cos\theta_2$

Where, T is the torque produced by the induction motor, φ is flux responsible for producing induced emf, I_2 is rotor current, $\cos\theta_2$ is the power factor of rotor circuit.

The flux φ produced by the stator is proportional to stator emf E_1. i.e $\varphi \propto E_1$

We know that transformation ratio K is defined as the ratio of secondary voltage (rotor voltage) to that of primary voltage (stator voltage).

$$K = \frac{E_2}{E_1}$$

$$or,\ K = \frac{E_2}{\phi}$$

$$or,\ E_2 = \phi$$

Rotor current I_2 is defined as the ratio of rotor induced emf under running condition , sE_2 to total impedance, Z_2 of rotor side,

$$i.e\ I_2 = \frac{sE_2}{Z_2}$$

and total impedance Z_2 on rotor side is given by ,

$$Z_2 = \sqrt{R_2^2 + (sX_2)^2}$$

Putting this value in above equation we get,

$$I_2 = \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

s = slip of induction motor. We know that power factor is defined as ratio of resistance to that of impedance. The power factor of the rotor circuit is

$$\cos\theta_2 = \frac{R_2}{Z_2} = \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Putting the value of flux φ, rotor current I_2, power factor $\cos\theta_2$ in the equation of torque we get,

$$T \propto E_2 \frac{sE_2}{\sqrt{R_2^2 + (sX_2)^2}} \times \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Combining similar term we get,

$$T \propto sE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

Removing proportionality constant we get,

$$T = KsE_2^2 \frac{R_2}{\sqrt{R_2^2 + (sX_2)^2}}$$

$$This\ comstant\ K = \frac{3}{2\pi n_s}$$

6 | 6

II.7.

In some high rating transformer, one winding in addition to its primary and secondary winding is used. This additional winding, apart from primary and secondary windings, is known as Tertiary winding of transformer. Because of this third winding, the transformer is called three winding transformer or 3 winding transformer. Tertiary winding is provided in electrical power transformer to meet one or more of the following requirements-

It reduces the unbalancing in the primary due to unbalancing in three phase load.

It redistributes the flow of fault current.

Sometime it is required to supply an auxiliary load in different voltage level in addition to its main secondary load. This secondary load can be taken from tertiary winding of three winding transformer.

As the tertiary winding is connected in delta formation in 3 winding transformer, it assists in limitation of fault current in the event of a short circuit from line to neutral. 6 | 6

PART - C

III.

(a) Transformation ratio , $K = V_2 / V_1 = N_2 / N_1 = 1/6$

Equivalent resistance referred to primary $= R_1` = R_1 + R_2 / K^2$

$= 0.9 + [0.03 / (1/6)^2] =$ **1.98Ω**

Equivalent reactance referred to primary $= X_1` = X_1 + X_2 / K^2$

$= 5 + [0.03 / (1/6)^2] =$ **9.68Ω**

Equivalent impedance $Z_1` = [(R_1`)^2 + (X_1`)^2]^{1/2} =$ **9.88Ω**

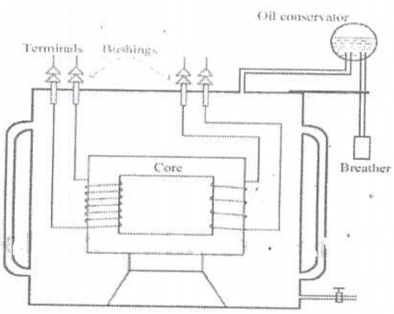
Primary current $I_1 = KI_2 = 1/6 \times 200 =$ **33.33A**

(a)The voltage to be applied to the high voltage side $V_s = I_1 Z_1`$

$= 33.33 \times 9.68 =$ **329.33V** 6+2 | 8

(b)power factor on short circuit $= R1`/Z1` = 1.98/9.88 =$ **0.2**

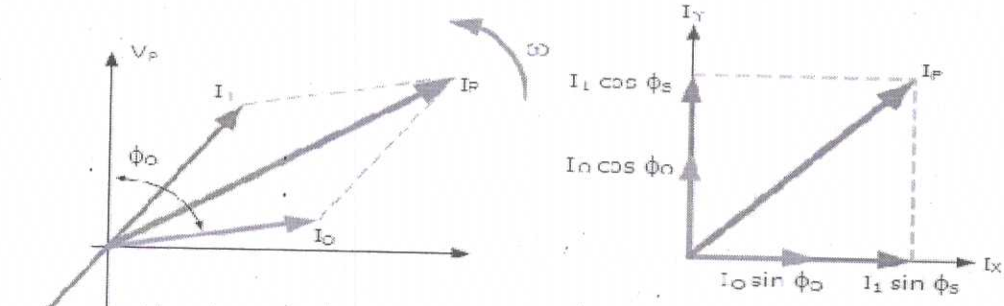
(b)



4

Core, Windings, Insulating materials, Transformer oil, Conservator, Breather, Tap changer, Cooling tubes, Buchholz Relay, Explosion vent — 3 — 7

IV. (a)



Horizontal Component, $I_X = I_O \sin\phi_O + I_1 \sin\phi_S$

Vertical Component, $I_Y = I_O \cos\phi_O + I_1 \cos\phi_C$

$$\therefore I_P = \sqrt{I_X^2 + I_Y^2} \quad \text{and} \quad \text{p.f.} = \cos\phi = \frac{I_Y}{I_P}$$

The total primary current is the vector sum of primary counter balancing current $I_1`$ and no load current $I_0$. There fore $I_1` = (N_2/N_1)\, I_2$. — 5+3 — 8

[vector diagram + explanation]

(b)

No load current = 5A, power factor = 0.2, primary induced emf = 240V
Frequency = 50Hz, no. of primary turns = 250
(a)Maximum value of flux in the core = 240 / (4.44.x 50x 250) = **4.32 mWb.**
(b)Core loss = 240 x 5 x 0.2 = **240W**
Energy component of no load current (Ie) = 5 x 0.2 = **1A** — 3x2+1 — 7
(c)Magntizing current (Im) = $[5^2 - 1^2]^{½}$ = **4.89A**

V. (a)

Open Circuit Test : The two components of no load current can be given as

$I\mu = I_0 \sin\Phi_0$ and $Iw = I_0 \cos\Phi_0$.

$\cos\Phi_0$ (no load power factor) = W / ($V1I_0$). ... (W = wattmeter reading)

From this, shunt parameters of equivalent circuit parameters of equivalent circuit of transformer (X_0 and R_0) can be calculated as

$X_0 = V_1/I\mu$ and $R_0 = V_1/Iw$.

(These values are referring to LV side of the transformer.)

Hence, it is seen that open circuit test gives core losses of transformer and shunt parameters of the equivalent circuit.

Short Circuit Test : The ammeter reading gives primary equivalent of full load current (Isc).The voltage applied for full load current is very small as compared to rated voltage. Hence, core loss due to small applied voltage can be neglected. Thus, the wattmeter reading can be taken as copper loss in the transformer.

Therefore, $W = Isc^2 Req$....... (where Req is the equivalent resistance of transformer)

$Zeq = Vsc/Isc$.

Therefore, equivalent reactance of transformer can be calculated from the formula $Zeq^2 = Req^2 + Xeq^2$.

These, values are referred to the HV side of the transformer.

Hence, it is seen that the short circuit test gives copper losses of transformer and approximate equivalent resistance and reactance of the transformer.
From this total loss can be measured by OC and SC test
Efficiency = output / input x 100
= output/ output + losses.
$= V_2 I_2 \cos\theta / (V_2 I_2 \cos\theta + Pi + x^2 Pe)$ — **3+3+2** — **8**
Regulation = $(I_2 R_2eq \cos\theta + I_2 X_2eq \sin\theta$/ no load voltage) X 100

(b)

Basic function of Instrument transformers is to step down the AC System voltage and current. The voltage and current level of power system is very high. It is very difficult and costly to design the measuring instruments for measurement of such high level voltage and current. Generally measuring instruments are designed for 5 A and 110 V. Instrument transformers are of two types –

Current Transformer (C.T.)

Potential Transformer (P.T.)

Current transformer is used to step down the current of power system to a lower level to make it feasible to be measured by small rating Ammeter (i.e. 5A ammeter).
Potential transformer is used to step down the voltage of power system to a lower level to make is feasible to be measured by small rating voltmeter i.e. 110 – 120 V voltmeter.
Their main application are

1. The large voltage and current of AC Power system can be measured by using small rating measuring instrument i.e. 5 A, 110 – 120 V.

2. Instrument transformers are used for protective circuits and also assure the safety of operators. — **3+3+1** — **7**

VI. (a)

From OC test

Supply voltage = 1100V, No load current = 0.5A

No load power factor , $\cos\theta = W_0/V_1I_0 = 55 / (1100 \times 0.5) =$ **0.1**

$\sin\theta =$ **0.995**

	energy component of no load current = 0.5 X0.1 = **0.05A** magnetizing component of current = 0.5 x 0.995 = **0.497A** no load resistance = 1100/0.05 = **22000Ω** no load reactance = 1100/ 0.497 = **2211Ω** **From SC test** Transformation ratio = 220 / 1100 = **1/5** Equivalent impedance ref. to sec. = 10/80 =**0.125Ω** Equivalent resistance ref. to sec. = $400/80^2$ = **0.0625Ω** Equivalent reactance ref. to sec = $[0.125^2 - 0.0625^2]^{1/2}$= **0.108Ω** When load current I2 = 100A, power factor = 0.8, **Voltage regulation** = $I_2R_2`\cos\theta + I_2X_2`\sin\theta / V_2$ = (100x0.0625x0.8 +100x0.108x0.6 / 220) X 100 = **5.67%** When supplying 100A at 0.8 pf Output = $V_2 I_2 \cos\theta$ = 220 x 100 x 0.8 = **17.6.KW** Copper loss = $400 \times (100/80)^2$ = 625W = **0.625KW** Iron loss = 55W = **0.055KW** Input = 17.6 + 0.625 + 0.055 = **18.280KW** **Efficiency** = 17.6 / 18.28 X 100 = **96.7%**	4+4	8
(b)	The weight of the copper is proportional to the length and area of a cross section of the conductor. The length of the conductor is proportional to the number of turns, and the cross section is proportional to the product of current and number of turns. Now, the auto transformer, the weight of copper required in an auto transformer is Wa = weight of copper in section AC + weight of copper in section CB Therefore $W_a \propto I_1 (N_1 - N_2) + (I_2 - I_1)N_2$ $W_a \propto I_1N_1 + I_2N_2 - 2I_1N_2$ If the same duty is performed with an ordinary two winding transformer shown above in the figure (A) .The total weight of the copper required in the ordinary transformer. W_0 = weight of copper on its primary winding + weight of copper on its secondary winding. Therefore, $W_o \propto I_1N_1 + I_2N_2$ Now, the ratio of the weight of the copper in an auto transformer to the weight of copper in an ordinary transformer is given as		

$$\frac{W_a}{W_o} = \frac{I_1N_1 + I_2N_2 - 2I_1N_2}{I_1N_1 + I_2N_2}$$

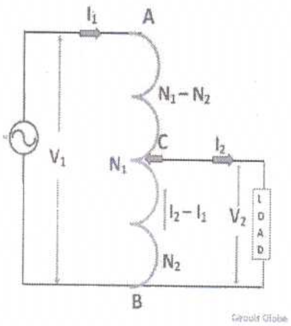
OR

$$\frac{W_a}{W_o} = \frac{I_1N_1 + I_2N_2}{I_1N_1 + I_2N_2} - \frac{2I_1N_2}{I_1N_1 + I_2N_2}$$

$$\frac{W_a}{W_o} = 1 - \frac{2I_1N_2/I_1N_1}{I_1N_1/I_1N_1 + I_2N_2/I_1N_1} = 1 - K$$

OR

$$W_a = (1 - K)W_o$$



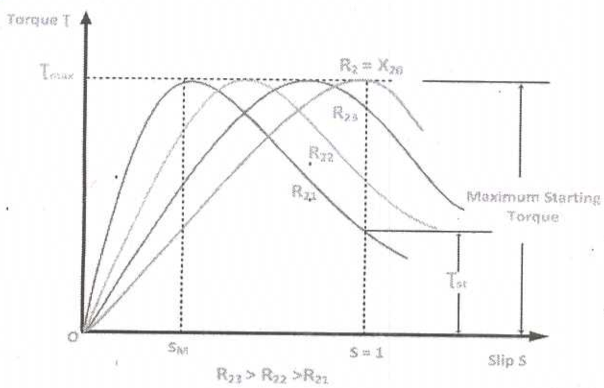
Saving of copper affected by using an auto transformer = weight of copper required in an ordinary transformer – weight of copper required in an auto transformer

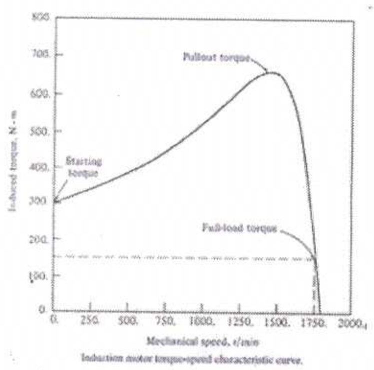
$$\text{Saving of copper} = W_o - W_a = W_o - (1 - K)W_o = KW_o$$

Therefore, Saving of copper = K x weight of copper required for two windings of the transformer. Hence, saving in copper increases as the transformation ratio approaches to unity. Hence the auto transformer is used when the value of K is nearly equal to unity. 7 7

VII. (a)

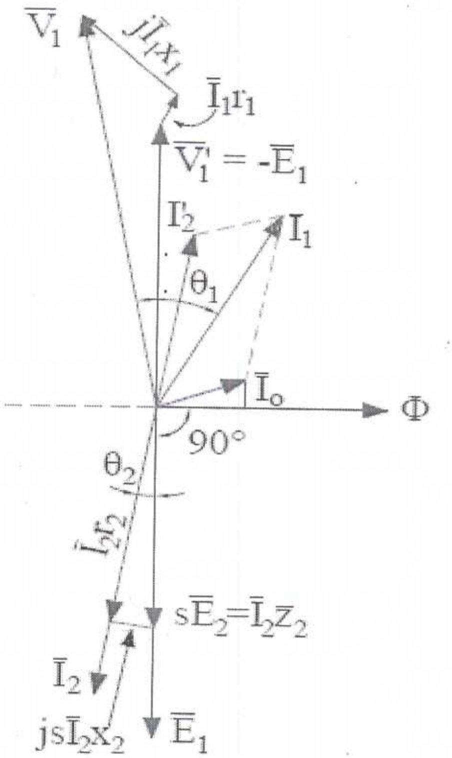
The Torque Slip Characteristic is represented by a rectangular hyperbola. For the immediate value of the slip, the graph changes from one form to the other. Thus, it passes through the point of maximum torque when $R2 = sX_{20}$. The maximum torque developed in an induction motor is called the Pull Out Torque or the Breakdown Torque. This torque is a measure of the short time overloading capability of the motor.

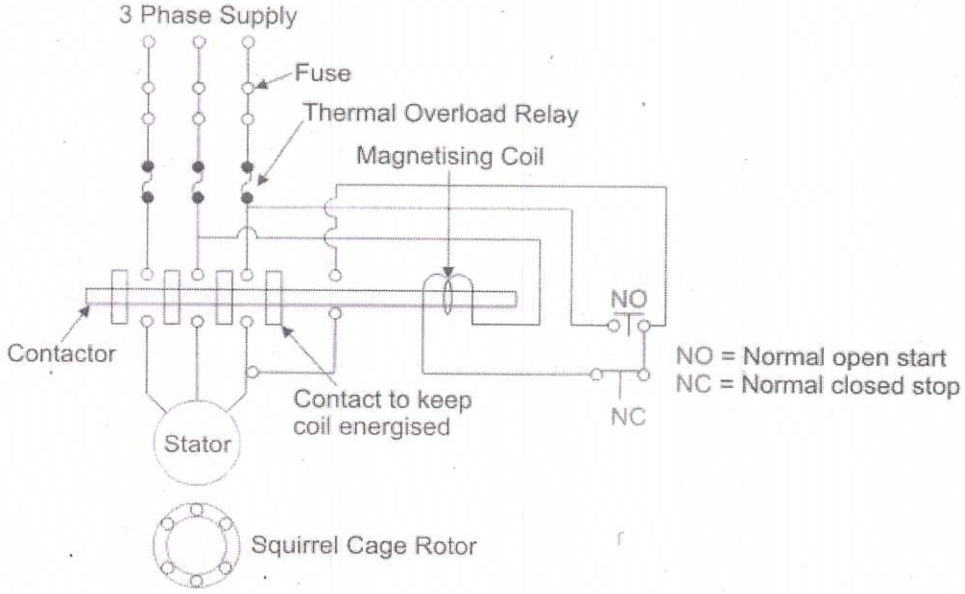
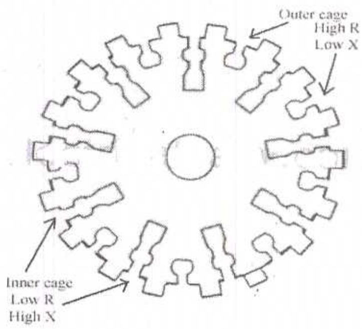




At the synchronous speed, s = 0, therefore, the torque is zero. When the speed is very near to synchronous speed. The slip is very low and $(sX_{20})^2$ is negligible in comparison with R2. Therefore, it is clear that the torque is proportional to slip. Hence, in the normal working region of the motor, the value of the slip is small. The torque slip curve is a straight line. As the slip increases, the speed of the motor decreases with the increase in load. The term $(sX_{20})^2$ becomes large. The term R_{22} may be neglected in comparison with the term $(sX_{20})^2$. Beyond the maximum torque point, the value of torque starts decreasing. As a result, the motor slows down and stops. At this stage, the overload protection must immediately disconnect the motor from the supply to prevent damage due to overheating of the

	motor. The induced torque in this region is small (just enough to overcome the motor's rotational losses) because the rotor magnetic field is quite small. When the motor is loaded down (Fig), the slip increases and the rotor speed falls. (sketch + explanation)	5+3	8
(b)	Supply frequency = 50Hz Rotor frequency (fr) = 100/60 = 5/3 (1)Slip S = fr / f = (5/3) / 50 = 0/033 = **33%** (ii)rotor speed N = Ns (1-S) = 120 x 50 /6 (1-0.033) = **967rpm.** (iii) mechanical power developed (Pmech) = (1-S) x rotor input = (1-0.033)x80 = **77.33KW** (iv) rotor copper loss per phase I_2^2R = 2667/3 =889W = **0.889KW** (v) rotor resistance per phase R = 889 / I_2^2 = 899/ 65^2 = **0.21Ω**	7	7
VIII. (a)	At standstill condition, $E_2 = I_2 (r_2 + jx_2)$. The core loss component of stator current Ic is in phase phase with. V_1' or $-E_1$. At standstill condition, the friction and windage loss is zero, therefore the stator no load current is given as $I_0 = I_m + I_c$ Since stator applied voltage V_1 must balance the stator back emf V_1' or $-E_1$, stator impedance drop $I_1(r_1 + jx_1)$, therefore we can write $V_1 = V_1' + I_1(r_1 + jx_1)$ Similar.equation exists for rotor circuit and can be written as $E_2 = I_2 (r_2 + jx_2)$ At full load, the slip s of induction is low. The stator voltage equation , do not changes when the motor is loaded. But the rotor voltage equation changes with slip. The rotor induced voltage at any slip s becomes sE_2 and the rotor circuit reactance becomes sx_2. Therefore $sE_2 = I_2 (r_2 + jsx_2)$ The above rotor equation when implemented, the induction motor phasor diagram will becomes different from the phasor at standstill condition. The induction motor phasor at full load slip s is shown below.		

	 (sketch + explanation)	5+3	8
(b)	Let external resistance per phase added to the rotor circuit be of \`r\`ohms. Rotor circuit resistance per phase R_2 =(0.02 +r) Ω Rotor circuit stand still reactance per phase X_2 = 0.1Ω Slip at starting , S = 1 Torque at starting will be maximum , when $R_2 / X_2 = S = 1$ or $R_2 = X_2$ or (0.02+r) = 0.1 External resistance per phase added\` r\` = 0.1 – 0.02 = **0.08Ω**	7	7
IX. (a)	A **DOL starter** (or **Direct On Line starter** or **across the line starter**) is a method of starting of a 3 phase induction motor. In DOL Starter an induction motor is connected directly across its 3-phase supply, and the DOL starter applies the full line voltage to the motor terminals. Despite this direct connection, no harm is done to the motor. A DOL motor starter contains protection devices, and in some cases, condition monitoring. A direct on line starter can only be used if the high inrush current of the motor does not cause an excessive voltage drop in the supply circuit. If a high voltage drop needs to be avoided, a star delta starter should be used instead. Direct on line starters are commonly used to start small motors, especially 3 phase squirrel cage induction motors. A wiring diagram of a DOL starter is		

	shown below:  [sketch + explanation]	5+3	8
(b)	Rotor of a double squirrel cage motor has two independent cages on the same rotor. The figure at left shows the cross sectional diagram of a double squirrel cage rotor.  Bars of high resistance and low reactance are placed in the outer cage, and bars of low resistance and high reactance are placed in the inner cage. The outer cage has high 'reactance to resistance ratio' whereas, the inner cage has low 'reactance to resistance ratio'. At starting of the motor, frequency of induced emf is high because of large slip (slip = frequency of rotor emf / supply frequency). Hence the reactance of inner cage ($2\pi fL$ where, f = frequency of rotor emf) will be very high, increasing its total impedance. Hence at starting most of the current flows through outer cage despite its large resistnace (as total impedance is lower than the inner cage). This will not affect the outer cage because of its low reactance. And because of the large resistance of outer cage starting torque will be large.As speed of the motor increases, slip decreases, and hence the rotor frequency decreases. In this case, the reactance of inner cage will be low, and most of the current will flow through the inner cage which is having low resistance. Hence giving a good efficiency. When the double cage motor is running at normal speed, frequency of the rotor emf is so low that the reactance of both cages is negligible. The two cages being connected in parallel, the combined resistance is lower.	7	7

X.

(a)

Input on load W0 = 600W, windage and friction losses Wf = 183W

Total stator core loss = W_0 – Wf = 600 – 183 = 417 W

Applied voltage per phase , V 400V, motor is delta connected

No load line current, I_l = 3A

No load phase current , $I_0 = I_{L0}/\sqrt{3} = 3/\sqrt{3} = \sqrt{3}$A

No load power factor , cos $\theta_0 = W_0 / (3\ VI_0) = 417 / 3x\ 400\ x\ \sqrt{3}$ =**0.2**

Energy component of **no load line current** = 3x0.2 = **0.6A**

Magnetizing component of current = $(32- 0.62)^{1/2}$ = 2.95A

Energy component of no load phase current(Ie) = I_0cos $\theta_0 = \sqrt{3}$ x 0.2 = 0.3464A

Then, **no load resistance** = V/I_0 = 400/0.3464 = **1155Ω**

Magnetizing component of no load phase current Im = 2.95 / $\sqrt{3}$ = 1.7A

No load leakage reactance = V/Im = 400/1.7 = **235Ω**

On short circuit voltage applied per phase = 200V

On short circuit stator line current = 12A

On short circuit , stator phase current = 12/ $\sqrt{3}$ = 6.928A

Input on short circuit, We = 1660W

Power factor on short circuit, = 1660/ (3 x 200 x6.928) **= 0.4**

Equivalent impedance = V_0/Is =200/6.928 = **28.85Ω/ phase**

Equivalent resistance = Ws/ 3Is2 = 1660/ 3(6.928)2 = **11.54Ω/ phase**

Equivalent reactance = (28.852 – 11.542)1/2 = **26.5Ω/phase** **1x8** **8**

(b)

Induction motors are used at various places. Speed control of induction motors is quite difficult and that's why their use was restricted and DC motors had to be used as their speed regulation was possible. But when induction motor drives were invented and implemented, they were given preference because of many advantages over DC motors. Whenever controlling of motors is done, braking is

	the most important term, so as with induction motors. Induction motor braking can be done by different methods, which are Regenerative braking of induction motor Plugging Braking of induction motor Dynamic braking of induction motor is further categorized as AC dynamic breaking Self-excited braking using capacitors DC dynamic braking Zero Sequence braking ******************	7	7